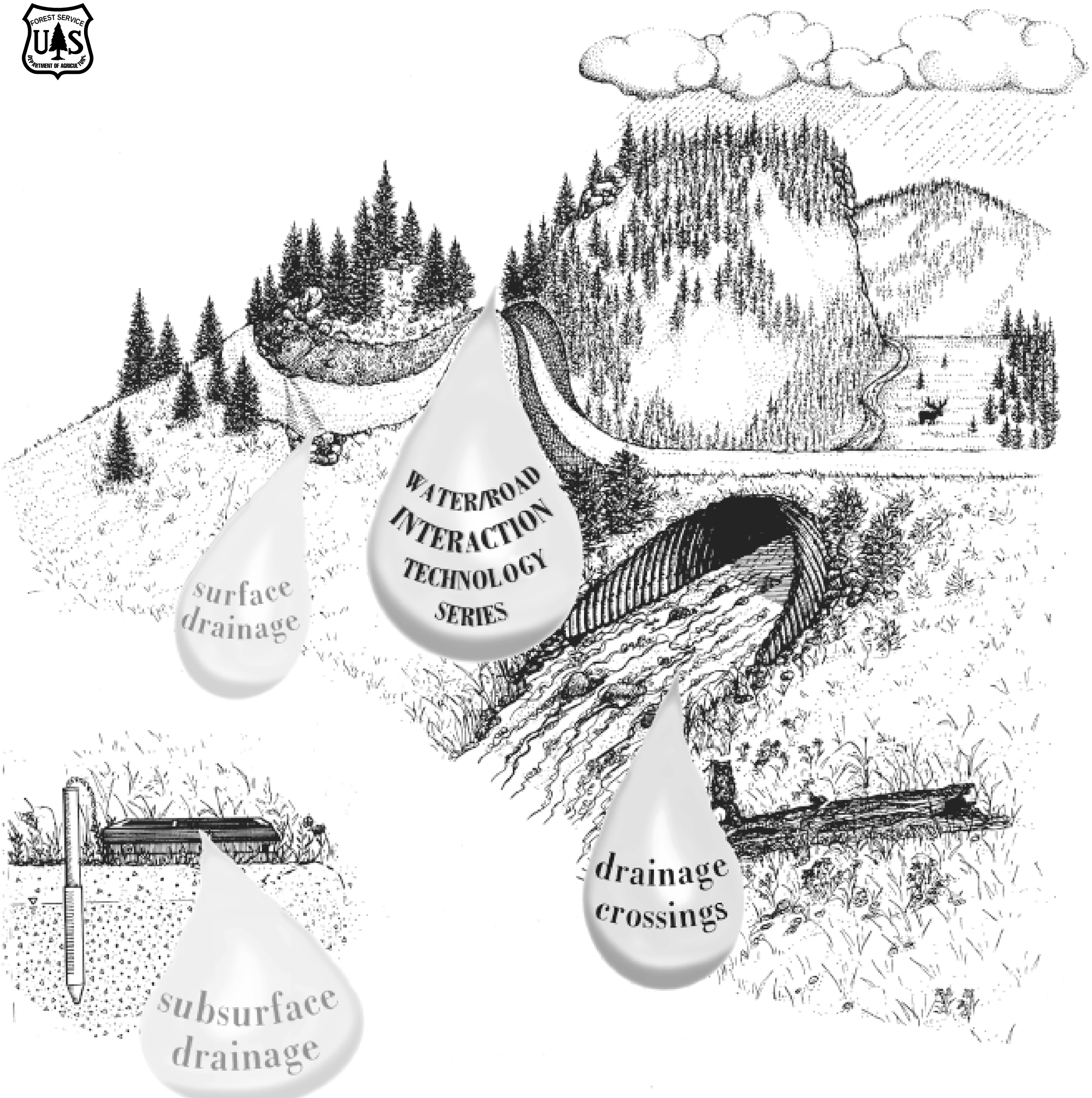
United States
Department of
Agriculture

Forest Service

**Technology &
Development
Program**

7700—Transportation System
2500—Watershed and Air Management
December 1997
9777 1814—SDTDC

Diversion Potential at Road-Stream Crossings



Diversion Potential at Road-Stream Crossings

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DIVERSION POTENTIAL AT ROAD-STREAM CROSSINGS

INTRODUCTION

Rarely can roads be designed and built that have no negative impacts on streams. Roads modify natural drainage patterns and can increase hillslope erosion and downstream sedimentation. Sediments from road failures at stream crossings are deposited directly into stream habitats and can have both on-site and off-site effects. These include alterations of the channel pattern or morphology, increased bank erosion and changes in channel width, substrate composition, and stability of slopes adjacent to the channels. All of these changes result in important biological consequences that can affect the entire stream ecosystem. One specific example involves anadromous salmonids, such as salmon and steelhead, that have complex life histories and require suitable stream habitat to support both juvenile and adult life stages. A healthy fishery requires access to suitable habitat that provides food, shelter, spawning gravel, suitable water quality, and access for upstream and downstream migration. Road-stream crossing failures have direct impacts on all of these components.

The physical consequences of exceeding the capacity of stream crossings in wildland environments usually depends on the degree of exceedance, crossing fill volume, fill characteristics, soil characteristics, and the flowpath of overflowing stream discharge. This paper examines the last determinant, the flowpath of overflowing water and associated load. Stream crossings frequently have the potential to divert streams from their channel if the capacity of the crossing structure is exceeded. Road-stream crossings with diversion potential typically pose much greater overall risks than those without diversion potential. Designing roads to avoid diversion potential is straightforward, and remediating existing crossings to correct diversion potential is usually inexpensive. This paper discusses the physical effects of diversion potential, and provides design considerations for remediation of existing crossings that have diversion potential.

CROSSING CAPACITY AND CONSEQUENCES MUST BE EVALUATED SEPARATELY

In evaluating risks to water quality and aquatic and riparian resources, it is useful to separate the *capacity* of the crossing structure—the amount of water, debris and sediment the structure can pass—and the *consequences* of capacity exceedance—what erosion and sedimentation are likely to occur upon exceedance. Those responsible for designing road-stream crossings are often primarily concerned about the capacity of the structure while those responsible for managing downstream aquatic and riparian habitats are more concerned about the consequences. All stream crossings have the probability to fail. Thus, design and assessment of existing structures must take this into account and minimize the potential consequences of failure, regardless of capacity.

WHAT IS STREAM DIVERSION POTENTIAL?

A stream crossing has diversion potential if, when stream crossing capacity is exceeded (i.e., the culvert plugs), the stream would back up behind the fill and flow down the road rather than flow directly over the road fill and back into the natural channel (Weaver and Hagans 1994). Diversion potential exists on roads that have a continuous climbing grade across the stream crossing or where the road slopes downward away from a stream crossing in at least one direction (figure 1). A crossing without diversion potential may breach the crossing fill if it overtops, but the stream will not leave the natural channel (figure 2). In almost all cases, diversion will create a greater erosional consequence of capacity exceedance than streamflows that breach the fill but remain in the channel.

Stream diversion can also be caused by accumulations of snow and ice on the road that will direct overflow out of the channel (Fred Swanson, personal communication). Snow removal operations need to consider this potential effect and configure removed snow such that stream diversion will not occur.

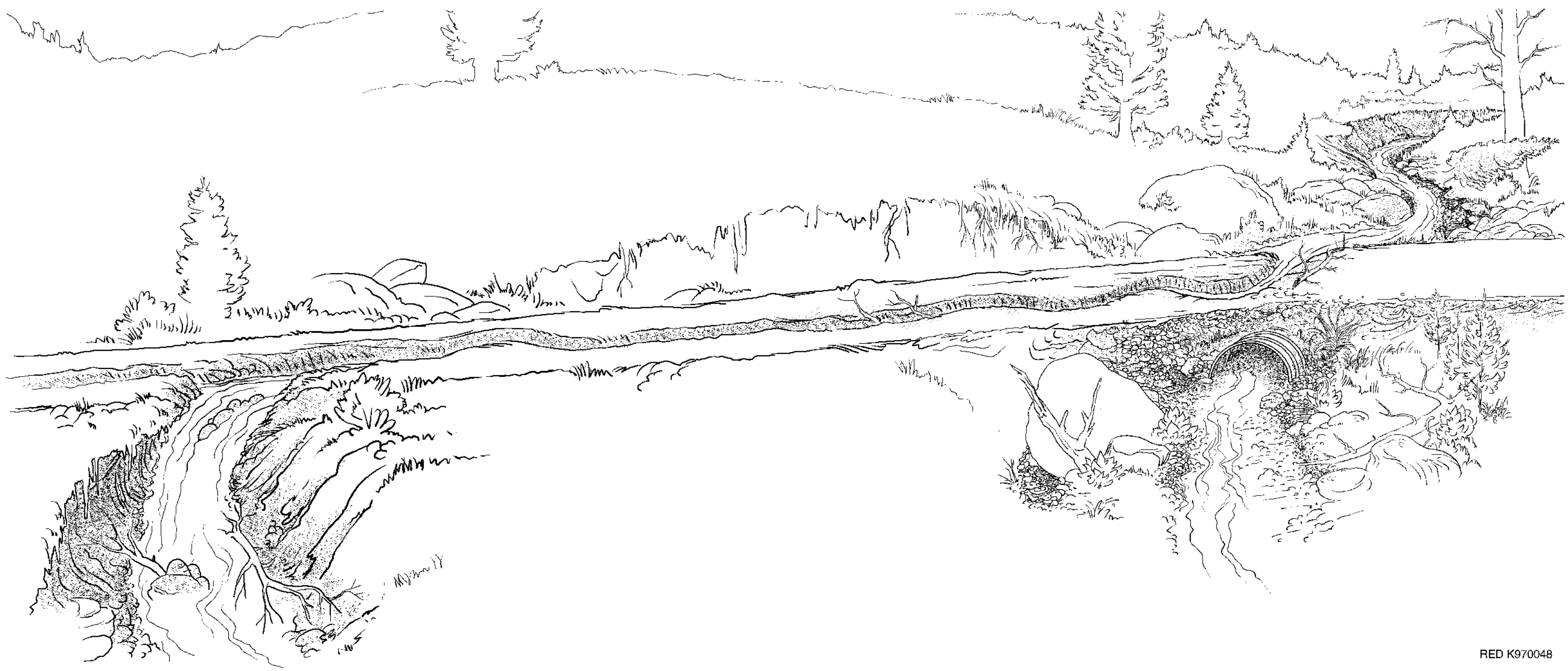

Figure 1—The probability of failure is substantial for most crossings, so how they fail is of critical importance. In this sketch, the crossing has failed, and the road grade has diverted the streamflow out of the channel and down the road, resulting in severe erosion and downstream sedimentation. Such damage to aquatic habitats can persist for many years once begun.

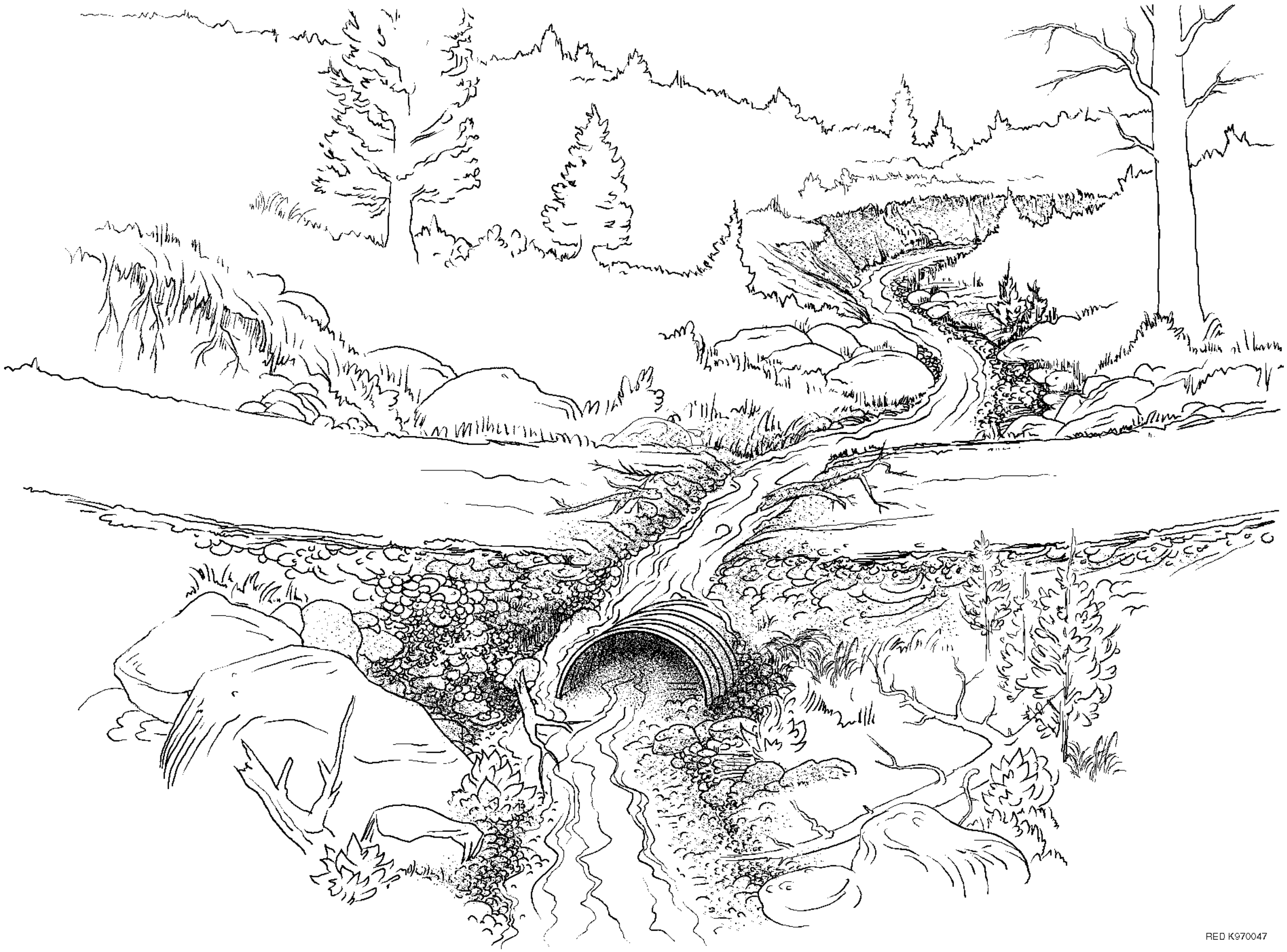

Figure 2–Stream diversions are easy to prevent. In this sketch the road grade was such that a crossing failure only caused the loss of some road fill (Furniss et al. 1991).

In debris flow-prone landscapes, stream flows can be diverted when the debris flow deposits material across the roadway. In such instances, streamflow can be shunted down the road even though the road was configured to avoid diversion. Crossings can be configured to address this problem chiefly by anticipating debris flows and providing an adequate grade dip at the crossing to accommodate debris outruns without stream diversion.

EFFECTS

In most places, the potential erosional consequences of road-stream crossings that have diversion potential are greater than for stream crossings with no diversion potential (Best et al. 1995) (figure 3).

Stream diversions usually do not correct themselves or “heal.” Where roads are abandoned or infrequently visited or maintained, stream diversions continue and sediment yields will be elevated for long periods, perhaps for decades (figure 4). A sediment budget in the Garret Creek watershed in northern California revealed that stream diversion at road-stream crossings was the greatest source of fluvial erosion. Eroded volumes from diversions approached streamside landslides as the dominant source of erosion (Best et al. 1995). Diversion of streams by road-stream crossings has been identified as a long-term source of cumulative effects in wildland watersheds of northern California. In the lower Redwood Creek basin of northwest California, Weaver et al. (1995) found at least 95 percent of the total volume of gully erosion was attributable to stream diversions at road and skid-trail crossings.

Recent surveys of the effects of large floods in the Pacific Northwest (Furniss et al., in preparation, Chris Park, personal communication) found that stream diversion at road-stream crossings was the predominant mechanism of road damage and accounted for the largest amounts of fluvial erosion in the surveyed areas.

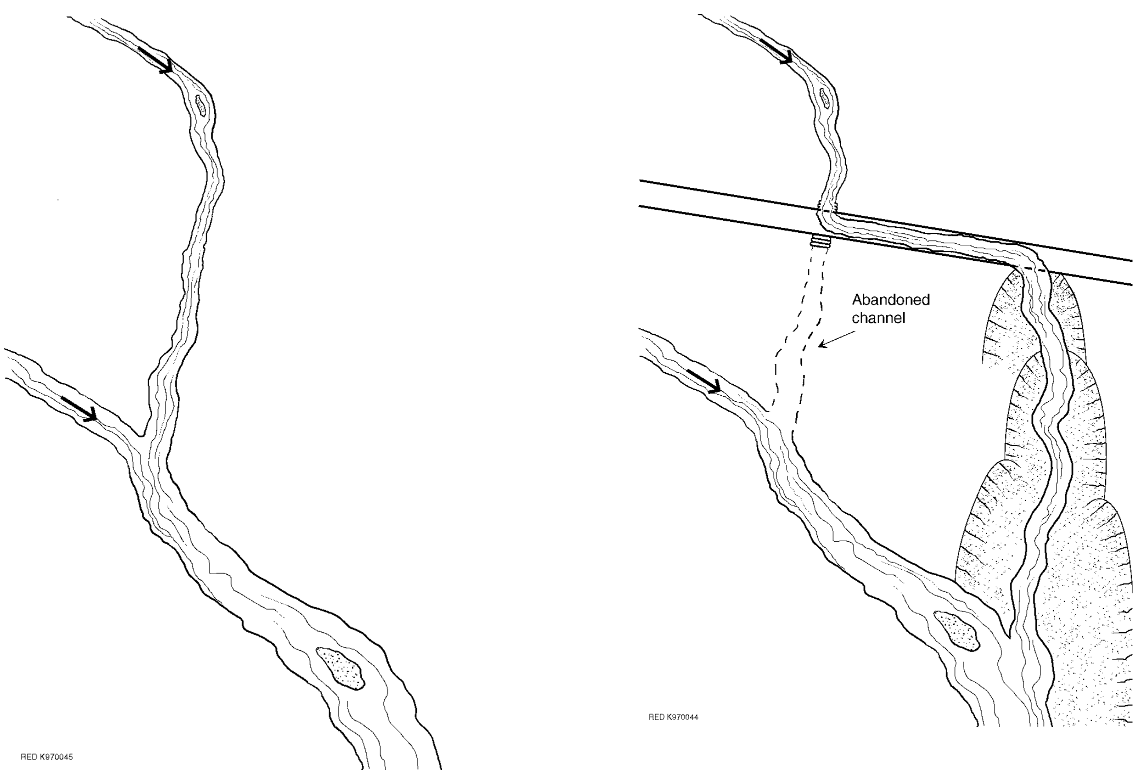

Figure 3—The erosional consequences of diverting streamflow onto nonstream slopes are usually large, as a stream (gully) will become incised into the receiving terrain. Often landslides of debris flows can be triggered by the loading of nonstream slopes with excess water and undermining of slope support by gully incision.

Physical Consequences of Stream Channel Diversion by Road Drainage Structures

Incision of a New Stream Channel

Where diverted water runs down the road or ditch and then onto a natural slope, a new stream channel will be incised to accommodate the flows. This can involve large amounts of erosion as a new stream channel is cut. The process, if unchecked, will go on for long periods, often for years or decades. In places where roads are abandoned or infrequently inspected, this process can produce large and persistent water quality impacts. Actual erosion volume would depend on the distance of diversion, the erodibility of the road and receiving slopes, erosivity of the streamflows, and the length of time the diversion is allowed to persist.

Initiation of Road Fill Failures

Sidecast fill failures are a common consequence of diversion. In steep terrain with extensive sidecast materials associated with roads, diverted flows often initiate landslides. These landslides can initiate debris torrents and have consequences extending far down the basin.

Enlargement of the Ditchline

Where the ditch must carry much or all of the streamflow, it will likely become enlarged as the flows scour a larger cross section (figure 5).

Diversion of Flow to Adjacent Watersheds and/or Drainage Structures – Cascading Failures

Flows can be diverted to adjacent watersheds as they are diverted down roads or ditchlines. This causes an increase in the peak flows of the receiving channel and consequent erosion. Under some conditions enlargement of the channels receiving diverted flows occurs, with very large increases in erosion and sedimentation and loss of riparian habitats. Downslope road drainage structures, including cross drains, can easily suffer capacity exceedance when diverted streamflow enters them. An initial diversion can set in motion a “cascading failure” as the diverted flows enter and overwhelm consecutive drainage structures (figure 6).

Figure 4—Diversions cause long-term gullying and damage to soil and watershed resources on both abandoned and maintained roads.

Figure 5—Enlargement of a roadside ditch as a result of stream diversion. The receiving channel (not pictured) has received both sediment and additional runoff as a result of stream diversion.

Figure 6—Cascading failure. Diverted flows from crossing A overwhelms crossing B, which also diverts to another crossing (not shown).

OCCURRENCE OF DIVERSION POTENTIAL

Diversion potential at road-stream crossings is common in the Pacific Northwest. Inventory data of 1,992 road-stream crossings on federally managed lands in northwest California and the Oregon Cascades show that, upon capacity exceedence, 56 percent will divert stream flows out of the channel and down the road or ditch some distance (figure 7a). Here, diversion potential is expressed as the length the diverted water would travel along the road or ditch. (USDA Forest Service, unpublished data).

Diversion potential is more likely to occur on insloped roads than outsloped roads because of the presence of the inboard ditch and the orientation of the road bed, which tends to keep flows moving down the road rather than across the road (Best et al., 1995). In some areas, recent regulations have prohibited constructing roads with diversion potential (e.g., USDI and USDA 1994). However, these regulations often do not explicitly address cross drains. Diversion potential at cross drains is similar to stream crossings (figure 7b). In many instances, such as where roads maintain a steady, climbing grade, adjacent cross drains will be susceptible to cascading failures from adjacent, upslope diversions. Cascading failures often increase in magnitude with distance from the initial failure as additional water, sediment, and debris are added to the flow and erosivity “snowballs” along the diversion path.

Further, replacing the culvert with an “oversized” culvert has been interpreted to be adequate to mitigate diversion potential even though the physical feature that allows for diversion at the road crossing has not been treated. Reducing the *probability of failure* by increasing culvert *capacity* will reduce overall risk, but *consequences of failure* should be addressed first. Treating the consequences of failure by eliminating diversion potential in the design and upgrading of roads is a direct and effective way to reduce risk.

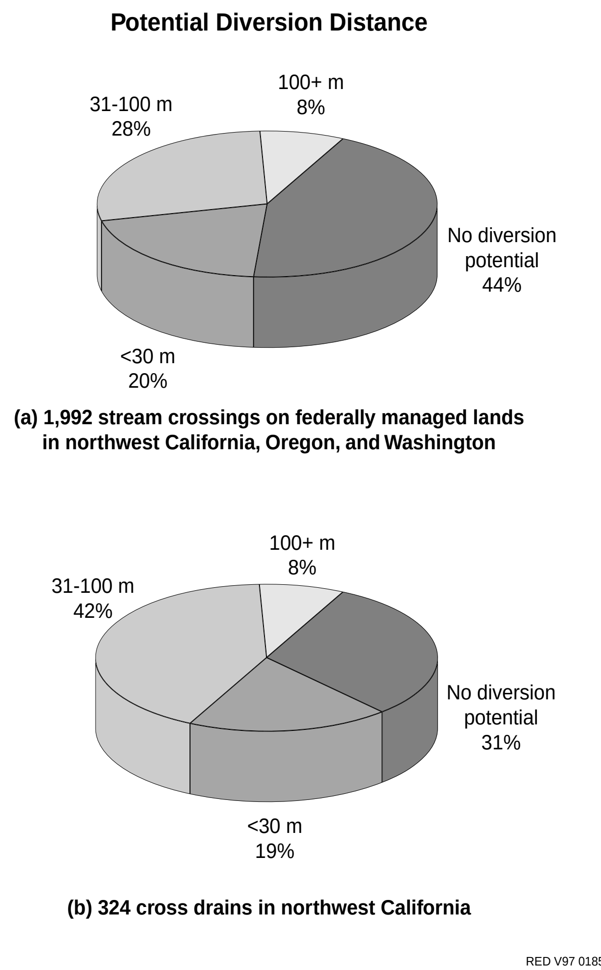

Figure 7—Potential diversion distance for (a) 1,992 stream crossings on federally managed lands in northwest California, Oregon, and Washington and (b) 324 cross drains in northwest California (USDA Forest Service, unpublished data).

INVENTORY OF ROAD-STREAM CROSSING DIVERSION POTENTIAL

Recognizing diversion potential during field inventory is relatively simple. Field personnel need only evaluate the low point of the road over the crossing structure compared to surroundings to determine where water will flow should the crossing pond water and overtop. Subtle slopes may control the routing of overflowing water and may require more careful examination on low-gradient roads.

A diversion inventory may be included with other surveys on crossings, such as maintenance needs or crossing characteristics for risk assessment, or it may be taken alone. A simple assessment of diversion potential will typically take less than 5 minutes per crossing.

Important features of diversion potential include:

- Presence or absence (This attribute is the only one on this list that is 'stable' data. The other features can change with road maintenance and storms.)

- Diverting feature (road or ditchline)

- Potential diversion distance (how far will the water flow before entering its original channel or another existing channel)

- Potential receiving feature (e.g., sidecast fill, hillslope, next downslope crossing or ditch-relief structure, adjacent stream channel)

- Estimated potential erosional consequences

DESIGNING CROSSINGS TO AVOID STREAM DIVERSION POTENTIAL

Roads should be located, designed, and maintained with full consideration of the consequences of design flow exceedance. An important part of this is to design the path the streamflow will take upon exceedance, such that erosional consequences of exceedance are minimized. During road location, the road should be located such that the road grade rises away from the crossing at each approach. Where roads climb through small streams, rolling the grade (i.e., designing the crossing as a 'sag' vertical curve) to prevent stream diversion is usually the best technique. For very steep road grades, where a rolling dip is not feasible, rolling the cross-slope out to lead water off at or near the crossing can be used. In some cases this will involve designing a short diversion to route overflow to the least erodible location before it reenters the channel.

Remediating Existing Stream Diversion Potential

For low standard forest and rangeland roads, where grades are less than 5 percent, treatments to prevent stream diversion are straightforward and usually inexpensive. The cost is even less when compared to the cost of repairing roads and the environmental damage after diversions have occurred. For example, construction of rolling dips on low standard roads in Redwood National Park to eliminate diversion potential at 91 crossings took 0.7 hours per dip (Smith 1997).

In many cases, the solution is to construct a structure that will intercept overflow and prevent it from moving out of the channel. A rolling dip, or simple diversion prevention dip (DPD) will eliminate stream diversion potential (figure 8). For very small stream crossings and for cross drains, a waterbar may suffice. Rolling dips should not be constructed over the crossing. Rather, the dip should be placed on the downhill side of the crossing to avoid being overwhelmed by debris flows that may bury the dip and cause diversion. Culverts placed under low fills also cannot accommodate a dip constructed over the crossing.

DESIGN CONSIDERATIONS FOR DIVERSION PREVENTION DIPS

Expected Consequences

An analysis of the consequence of each crossing with diversion potential should be made and decisions on remediation made accordingly. Criteria for this will include:

- Potential erosional consequence

- Value of downstream resources

- Sensitivity of downstream resources to erosion and sedimentation

- Costs to repair road if diversion occurs

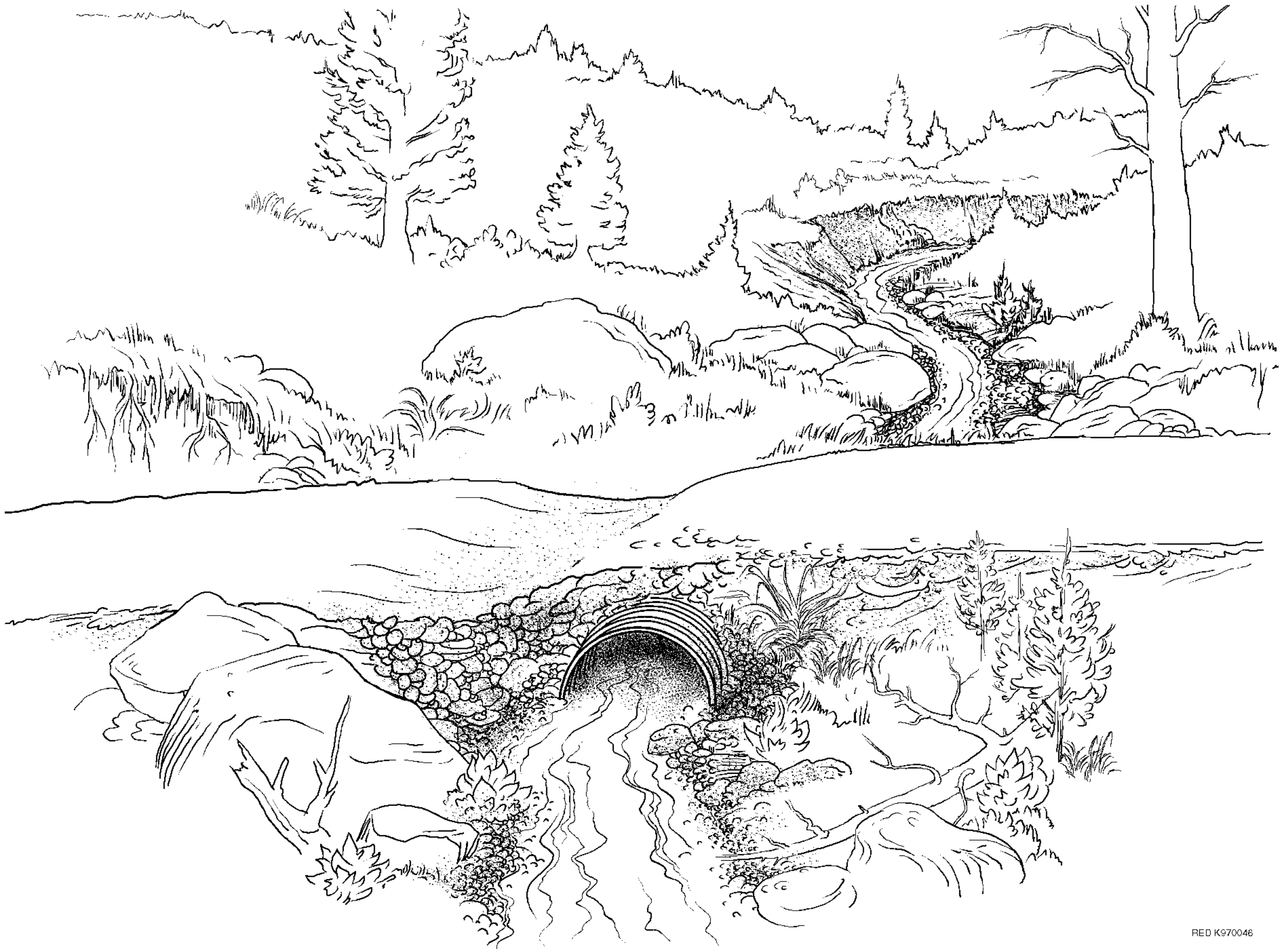

Figure 8—Construction of a dip to intercept overtopping flows and prevent diversion down the road or ditchline. This sketch depicts a diversion prevention dip on a low volume, low speed, single-lane road. The dip should intercept any ditchline present, and be of sufficient capacity to handle the entire expected design peakflow. Special care should be exercised in constructing the beginning (upslope end) of the dip where the rediversion of streamflow back toward the channel must occur and persist.

- Inspection and maintenance frequency of road and crossing

- Diversion of streamflow out of the basin.

Standard of Road

On low standard roads, a short, abrupt change in grade as a result of a diversion dip will generally be more acceptable than on higher standard roads where grade changes may need to be more gradual (Hafterson 1973). On higher standard roads, correcting diversion potential can be accomplished with longer rolling dips or with specialized structures designed for particular sites.

Hydraulic Capacity of Diversion Prevention Dips

The DPD must be designed to accommodate the entire design flow for the crossing structure. The dip should have sufficient depth to ensure that the water elevation of the overtopping flows is less than the lower edge of the dip. Two approaches exist for calculating DPD hydraulic capacity. The first approach treats the dip as an open channel and uses the slope-area method to determine the discharge given dip slope, dip cross sectional area, and an estimate of Manning's n for the road surface through the dip. The second approach treats the dip as a broad crested weir and uses discharge coefficients for graveled road surfaces. This procedure is outlined by Hulsing (1996). The two approaches produce similar results. Hydraulic capacities presented in figure 9 use the slope-area approach. A thorough discussion of dip design is given by Hafterson (1973).

The skew angle of the dip is key in determining hydraulic capacity. The turn the water must make from ditch to dip should be minimized to reduce head loss and erosion of the dip berm. This point where the dip berm and road cut intersect should be durable, using armoring or "overbuilding" to ensure that streamflows are effectively and persistently rediverted toward the stream channel.

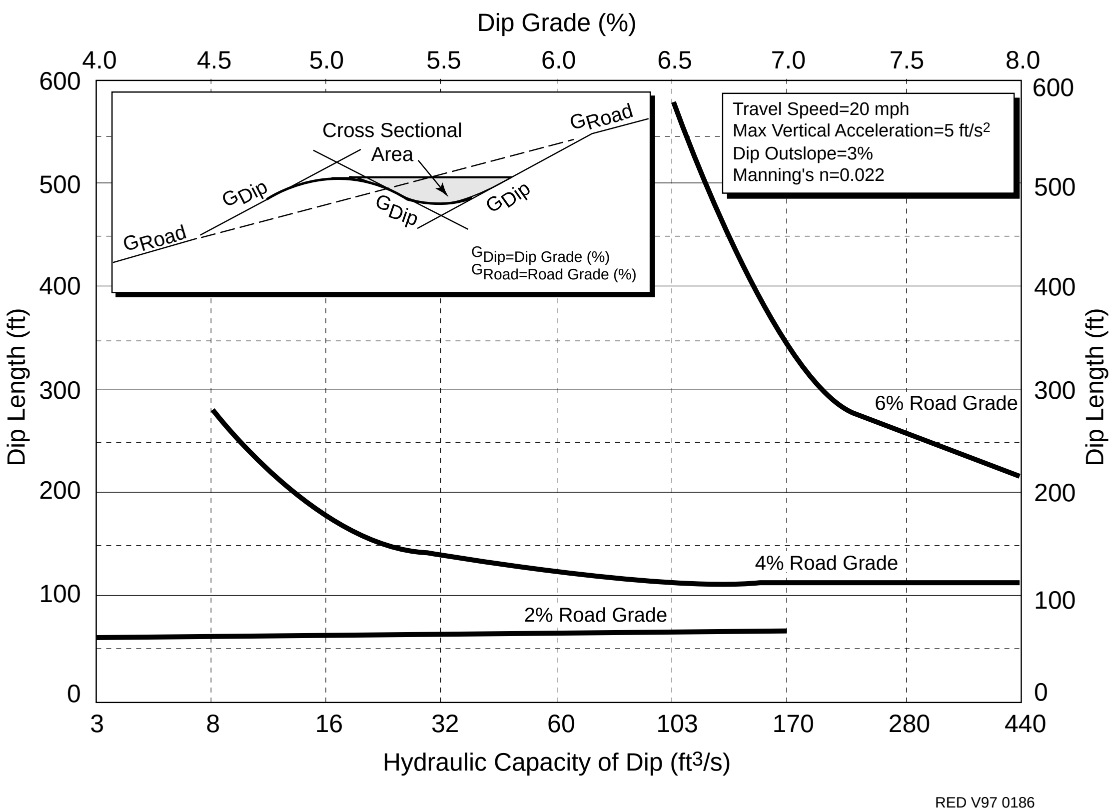

Figure 9—Hydraulic capacity and length of disturbed road for broad based drainage dips constructed with circular arcs. The approach and descent grades are assumed to be equal. Under such assumptions, hydraulic capacity is dependent solely on the dip grade and was estimated using Manning's Equation. The hydraulic capacity can be increased without changing the dip grade by simple design modifications. Dip length is a function of the dip grade and the preexisting road grade.

Greater road grades require either a greater depth of dip or longer section of excavation to accommodate the expected flows. Dips should not be constructed on sites having a preexisting road grade greater than 12 percent. Outsloping through the dip should not exceed 4 percent. For steep roads the dip skew angle must be reduced.

Placement

Dips should be placed just downslope of the crossing. This is important for avoiding debris flows that may fill in the dip and cause diversion. Where culverts are installed in a shallow fill, locating the dip directly over the crossing is not feasible. In some cases, a short diversion to route diverted flows onto stable ground before reentering the natural channel will be necessary.

SUMMARY

Road-stream crossings present risks to water quality and to aquatic and riparian habitats. Therefore, crossing design must consider not only capacity but the potential erosional consequences of failure as well. Stream diversion at road-stream crossings, when overtopping flows leave their natural channel, represents an unnecessarily large potential erosional consequence. Eliminating diversion potential at road-stream crossings is typically inexpensive and straightforward. By keeping overtopping flows in their natural channel, large erosional and depositional consequences can be minimized, reducing adverse impacts to water quality and to aquatic and riparian habitats.

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